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CAPTAIN USAF

MASTER OF PUBLIC HEALTH

A DESCRIPTION OF THE LEVELS OF RADIOACTIVITY IN DRINKING WATER FROM SIXTY-FOUR COMMUNITIES (1974-1979)

UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT HOUSTON, TEXAS
SCHOOL OF PUBLIC HEALTH

A DESCRIPTION OF THE LEVELS OF RADIOACTIVITY IN DRINKING WATER FROM SIXTY-FOUR COMMUNITIES (1974-1979)

By

John Robert Stockwell

APPROVED:

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To Helen

A DESCRIPTION OF THE LEVELS OF RADIOACTIVITY IN DRINKING WATER FROM SIXTY-FOUR COMMUNITIES (1974-1979)

by

JOHN ROBERT STOCKWELL, B.S., M.D.

THESIS

Presented to the Faculty of The University of Texas
Health Science Center at Houston
School of Public Health
in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF PUBLIC HEALTH

THE UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT HOUSTON
SCHOOL OF PUBLIC HEALTH
Houston, Texas
June, 1980

PREFACE

"Everybody wants you to pick it up,

but nobody wants you to put it down"

Louie Welch

Former Mayor of Houston

May 30, 1980

A DESCRIPTION OF THE LEVELS OF RADIOACTIVITY
IN DRINKING WATER FROM SIXTY-FOUR
COMMUNITIES (1974-1979)

John Robert Stockwell, B.S., M.D.
The University of Texas, 1979

Supervising Professor: Alfonso H. Holguin

This study describes the levels of radioactivity in drinking water from sixty-four communities (1974-1979). Certain man-controlled factors may alter the levels of radioactivity in a community's water supply. The selection of water source, the type of water treatment, and the presence of local radioactive ground disposal sites are three examples of local features which might affect the level of radioactivity of finished water. In this study each community water supply studied was characterized by the selection of the original type of water source (i.e. reservoir or well), the presence or absence locally of conventional water treatment, and the presence or absence of a local radioactive ground disposal site. This study describes the relationship between two of these local features (source and disposal sites) and the levels of radioactivity in drinking water from these communities.

The health effects of low dose ionizing radiation and the hydrogeologic considerations involved in the ground disposal of radioactive wastes are reviewed. A history of early ground disposal operations and a history of the radiological surveillance of drinking water is presented.

This study failed to detect any association between the selection of the original type of water source and the levels of radioactivity in drinking water from these sixty-four communities (1974-1979). Likewise, there was no association detected between the presence of local radioactive waste disposal sites in certain of these communities and the levels of radioactivity in their drinking water.

ACKNOWLEDGEMENTS

The author is grateful for generous assistance received from various official agencies and from individuals with training and experience relevant to the radiological surveillance of drinking water. The Occupational and Environmental Health Laboratory and the Data Processing Branch of the Aerospace Medical Division (AMD), Brooks Air Force Base, Texas, have been especially cooperative. The Aeromedical Library, United States Air Force, Brooks AFB, Texas, has been the central library resource for this study.

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In the final revisi n and editing of this study, generous assistance was provided by the thorough reviews and specific suggestions for condensation, corrections and clarification. Review comments were obtained from Drs. Richard S. Howe, Clayton W. Eifler, and Alfonso H. Holguin.

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

Few environmental factors have greater impact on the individual's well being than the availability of an adequate potable water supply. Water that is not properly treated, or is contaminated in the process of distribution, can transmit microbiologic agents, chemicals, or toxins to a large number of persons. Additionally, because water assumes various characteristics and properties as it passes over and through the earth's surface, it may absorb various materials that can have significant health implications. Therefore, a properly controlled potable water supply is mandatory to maintain human life and sustain health.

"Water Quality" refers to the chemical, physical, biological and radiological characteristics of water with respect to its suitability for drinking. Historically, the primary concern for water quality focused on the first three characteristics of water. Increasingly, the radiological quality of public drinking water is of concern. This concern has two chief origins. On the one hand, there is an ever increasing volume and variety of radioactive wastes which are entering ground disposal sites. On the other hand, the relative uncertainty as to the health effects of very low dose ionizing radiation has resulted in current reevaluation.

Chapter II of this thesis contains a brief review of the literature in four areas of particular relevance. First, the health effects of low dose ionizing radiation will be briefly summarized. This will be followed by a few historical considerations of the radiological surveillance of water supplies. The literature review will then deal with the history of the operation for ground disposal of radioactive wastes. The final section of the literature review presents the hydrogeologic considerations which should be evaluated in the ground disposal of radioactive wastes.

Chapter III provides a general description of the radiological surveillance of drinking water conducted by the Air Force.

Chapter IV will describe the levels of radioactivity found in a group of sixty-four Air Force community water supplies for a six year period.

There are many physical, chemical, biological and geological factors which can affect the level of naturally occurring radioactivity in a community water supply. Experience suggests that certain man-controlled factors may alter the level of radioactivity in a community's water supply. The selection of water source (e.g. surface, well, or a mixture of the two); the type of water treatment; and the existence of local radioactive ground disposal sites are three examples of local features which might affect the level of radioactivity of finished water. In this study each community water supply studied characterized by source, treatment, and the existence of a local radioactive ground disposal site. This study will attempt to describe the association between the presence of these local features and the levels of radioactivity in drinking water from those communities.

Chapter V will be a general discussion.

CHAPTER II

LITERATURE REVIEW

Health Effects of Low Dose Ionizing Radiation

There is nothing new about the known health effects of radiation. What is new is the change in the willingess of society to accept physical risk, and an increasing desire to shift control of risk to the government. Wildovsky (1979) feels that the cultural reluctance to accept any physical risk could result in suboptimation of goals; in the pursuit of preserving the present, we hazard the c[illegible] risk of sacrificing the future. Perhaps a demand for "zero risks" becomes the greatest risk of all. This kind of argument may lose some appeal when applied to radiation risks. Since the long term effects of radiation are delayed for long periods, the initial sources of exposure may not be clearly identified. If the risk is unacceptable, identifying and eliminating or modifying any source is in order, because man may be at risk of effects which are essentially irreversible.

The delayed health effects of radiation are already well established, and no major new finding can be anticipated. The Japanese survivors of Nagasaki and Hiroshima and the Marshall Islanders, who were heavily exposed during the 1954 tests, have all been well studied. Children x-rayed *in utero*, persons treated for various diseases by radiation, uranium miners, victims of radiation accidents, early radiologists, et al. have provided a wealth of significantly exposed groups.

It has been common practice to assume a linear relation between radiation exposure and health risk. Therefore, the number of health effects predicted for a large population exposed at low level would approximate the experience of a small population exposed to a high level. Despite the fact that it has been the fundamental assumption of modern radioprotection practice for decades, the linear, non-threshold hypothesis is controversial. It has been hoped that an appropriate epidemiologic investigation of the linear, non-threshold hypothesis would resolve much of this controversy. There have been several attempts to test the association between increased cancer incidence and areas of high natural background radiation. Significant difficulty occurs with the description of actual exposures of broadly based population groups; this obstacle remains technically challenging. Ultimately, it may be possible to more clearly define sets of exposed and less exposed populations with characteristics such that large scale epidemiologic problems evaluating the role of high natural background radiation might become more manageable. To date, however, epidemiologic studies have not been able to demonstrate conclusively the effects of low dose radiation on health.

In some studies actual exposures have been incompletely categorized. For instance, some earlier epidemiologic investigations into the role of low dose ionizing radiation in inducing certain types of cancer (Mason and Miller,1974; Craig and Seidman, 1960) have limited their investigation to variations in cosmic ray distribution. These early studies found no correspondence in the magnitude of geographic variation of the skeletal dose rate from background radiation, and the potential exposure from radiation sources in the environment. The chief component of background assessed was cosmic radiation measured in the air, three feet above ground. Other important contributors to background radiation such as the radionuclide content of water were frequently ignored. Naturally occurring radioisotopes in water and food may be more important than cosmic rays in determining the skeletal dose received.

In two recent U.S. studies (Mason and Miller, 1974; Frigerio, Eckerman, and Stowe, 1975), an inverse relationship between background radiation and cancer rate has been shown. According to Frigerio _et al_. (1975) there is a consistent and continuous decrease in reported cancer mortality in states with a high "natural" background radiation, compared with those which have low "natural" background. Although there is no explanation for this, it should be noted that background radiation levels measured in this study were derived chiefly from variations in cosmic radiation, and other contributors to the "natural" background.

Although there is no explanation for this, it should be noted that background radiation levels measured in this study were derived chiefly from variations in cosmic radiation, and other contributors to the "natural" background, such as levels of radioactivity in water, were not accounted for.

The three most significant sources of radiation exposure for the general population are background radiation, medical diagnostic and therapeutic use of x-rays, and radiopharmaceuticals. Other sources include radioactive fallout from atmospheric testing of nuclear weapons and from technically enhanced natural radiation. The U.S. average natural background is about 130 mrem/yr.[1] A man-made background (medical, fallout, nuclear devices, etc.) of 40 mrem/yr should be added to the natural background. This 170 mrem/yr has most often been used as the basis for risk estimates. In many of the carcinogenesis risk estimates, radiation is assumed to be a pan- to polycarcinogen. i.e. all/many sites are subject to radiation carcinogenesis,

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[1]The rem reflects the fact that some types of radiation produce more biologic damage than others for a given amount of absorbed energy (rad).

1 millirem (mrem) = 10^{-3}rem.

The term rad, a more general unit applying to all types of ionizing radiation, measures the amount of energy absorbed in tissue or other material.

The Roentgen (R) measures the quantity of ionization per unit volume of air produced by x-rays or gamma radiation. Roentgens thus are units of exposure while rads are units of absorbed dose (Interagency Task Force on the Health Effects of Ionizing Radiation, June, 1979).

to about the same measure. If radiation is assumed to be a pancarcinogen, one would predict that malignancy incidence would increase with increasing background dose.

Gofman and Tamplin (1971) predict a one to thirty percent increase at 170 mrem/yr, assuming linearity. All currently accepted models for radiation associated carcinogenesis have assumed linearity. All have derived their results from small, selected populations, at high dose rates and, generally, at high dose levels. Extrapolation to zero has been assumed without consideration of dose rate.[2]

Frigerio (1975) maintains that not only is this approach wihtout observational basis, but that it is contradicted by a large body of radiological and toxicological data. Observation of actual populations at risk shows not only no increment but an actual decrement, leaving the no dose-linearity assumption without apparent observational support. Background radiation, as measured in two U.S. studies (Mason, 1974; Frigerio, 1975), has not been shown to be a carcinogen.

The biologic hazards of radiation are both somatic and genetic. Radiation alters the "information system" of proliferating somatic and germ cells in such a way that these cells pass on "bad or inadequate information", in the form of altered DNA, to their progeny. This change, a

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[2]Dose rate is the speed with which a given dose of radiation is delivered.

mutation, can result in cancer, cataracts, degenerative disorders, or nonspecific life shortening. Even though not all mutations are harmful, the chances are overwhelming that mutation of a germ cell will adversely affect the species, and not all mutations produce visible, immediately detectable effects. Half of the total damage produced by a single exposure may not be observed until 30 to 50 generations had elasped. Therefore, the absence of obvious health effects in exposed populations is no assurance that the degree of genetic damage due to low dose exposure has been small.

Fortunately, although the genetic hazards of radiation are significant, the major fraction of the dose received by man is somatic. The most important somatic hazard is carcinogenesis. For internally deposited radionuclides the "critical organ concept" is relevant. The "critical organ" is that organ in which damage from a given internally deposited radionuclide results in the greatest body injury. The "critical organ" is assumed to be the body organ in which there is the greatest concentration of the radionuclide. The dose for somati hazards are about an order of magnitude higher than the genetically significant doses received from the same background sources. The survival of the irradiated individual depends upon the critical organ dose received. Radiation hazards from areas of different levels of background radiation are better estimated from critical organ doses received. Concepts such as "whole body" dose are not as relevant as critical organ dose when considering carcinogenesis.

If it is reasonable to assume the linear non-threshold hypothesis and to extrapolate results of the studies of Japanese bomb victims, British spondylitic patients, and uranium miners to the U.S. population at large; it should also be acceptable to extrapolate the results of portions of the U.S. population to itself. Argonne National Laboratory (1973) demonstrated that the present evidence is incompatible with any increase of malignant mortality from an increasing background radiation.

In an attempt to reevaluate the validity of the linear non-threshold hypothesis, Brown (1976) has reviewed animal experiments, *in vitro* studies, and available human data as they pertain to the question of the shape of the dose-response curve for carcinogenesis. Brown suggests that most animal studies indicate that linear extrapolation from high doses overestimates the risks at low doses. In animal experiments which he reviewed, either dose fractionation or dose reduction usually results in fewer malignancies per rad than single acute exposure, but Brown cautions that these animal models may not be operative to human populations. Brown's review of *in vitro* studies of irradiated mammalian cells found a linear dose response curve. After reviewing animal experiments, *in vitro* studies of irradiated mammalian cells, and available human studies, Brown concludes that the risk estimates for low doses of radiation exposure are probably not less than risk estimates made for higher doses and that a linear extrapolation of the results of human exposure to high dose (of up to around 100 rads) to low dose exposures probably doesn't overestimate the risk at low doses. In fact, the risks at low doses may even be underestimated in some cases, according to Brown (see figure 1).

Much of the uncertainty in the health effect for low doses of ionizing radiation probably depends upon differences in types of radiation, dose rate and distribution, and total amount of exposure. Other important variables are host factors of radiosensitivity, physiological repair mechanisms, sex, age variation, critical organ, and general state of health. All of these factors interact in an exceedingly complex matrix of social, chemical, physical, and biological subsystems. The dynamics of these interactions are just beginning to be elaborated. The health impact attributable to low levels of exposure from natural environment (40 to 300 mrem) is probably indistinguishable from the occurrence of ill health due to other factors.

Three recent epidemiologic analyses (Interagency Task Force, 1979) suggest that low dose radiation exposure has a greater cancer effect than had previously been predicted by the linear non-threshold hypothesis. These analyses include data from populations with occupational exposures at the Department of Energy's Hanford Facility,

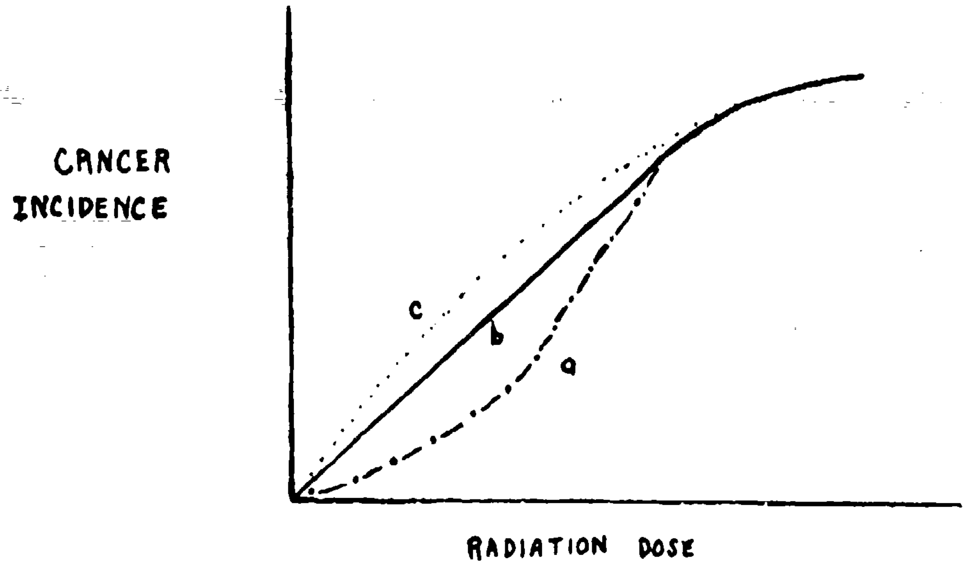

Figure 1

Dose Response Models for the Health Effects of Low Dose Ionizing Radiation

a. The linear quadratic dose response curve which reflects the hypothesis that cancer incidence is proportionately lower at lower doses than at higher doses, in part because cells may repair themselves more easily at low doses.

b. The linear hypothesis which assumes that the incidence of cancer at low doses is directly proportionate to the response at high doses, allowing one to extrapolate directly from known effects at high dose levels, to unknown effects at low dose levels.

c. Some recent results (see Section II of this study) suggest that the linear hypothesis, rather than being conservative, may underestimate the risk of cancer from radiation exposure by a factor of ten or more. The dose/response curve predicted by these studies might resemble line c.

This figure has been adopted from Section III. "Health Effects of Radiation" of the Report of the Interagency Task Force on the Health Effects of Ionizing Radiation, U.S. Department of Health, Education and Welfare, Washington, D.C., June, 1979.

the Portsmouth Naval Shipyard, and data from the Tri-State study of leukemia deaths (includes those exposed to diagnostic x-rays). There are two preliminary studies of populations exposed during the "SMOKY" nuclear weapons tests, and a study of childhood leukemia mortality in southern Utah. The implications of these most recent studies, if confirmed, could have far-reaching effects with respect to occupational standards and medical practices. One implication of the Hanford and Tri-State studies is that between 50 and 70% of all cancer would have to be attributed to background radiation. This is in stark contrast to the 1% estimates. The BEIR Committee (May 2, 1979) has analyzed these studies and finds them to be "unreasonable", in view of the assume role other environmental hazards are assumed to play in producing cancer.

In summary, most experts agree that any dose of radiation, no matter how low, involves some risk of cancer. The important question is not whether cancer may be caused by low dose exposure, but how much cancer is caused. The accepted model, to date, for the estimation of cancer incidence from radiation has been the linear, non-threshold hypothesis.

History of the Radiological Surveillance of Water Supplies

The possibility that environmental sources of radiation will become of greater public health concern is suggested by the first section of this literature review.

Increase use of radionuclides and nuclear power could escalate the potential of the environmental source. Routine environmental surveillance is a means for keeping informed about this situation. Although foodstuffs are a main source of radionuclide exposure, surveillance of air and water is also essential. Surveillance of air and water provides an early warning of impending problems to other parts of the environment. Air and water are the original means for environmental contamination. Prime consideration should be given to public drinking water supplies. No other municipal function is more critical for public health than an adequate, safe water system.

Radiological surveillance of drinking water primarily provides information of Gross Alpha Particle Activity and Gross Beta Particle Activity. Gross Beta Particle Activity is the total radioactivity due to beta particle emission inferred from measurements on a dry sample. Likewise, Gross Alpha Particle Activity is the total radioactivity due to alpha particle emission, again using a dry sample (usually Gross Alpha activity will include radium-226 but exclude radon and uranium). Frequently, a combined radium-226 and radium-228 determination is also obtained. Measurement of Gross Alpha and Gross Beta activity lacks specificity from the "critical organ" standpoint. For instance, if Gross Alpha or Gross Beta measurements in a community water supply were found to be elevated, a more detailed analysis of specific radionuclides in that water supply would be warranted, to identify the organ system most likely to be effected. However, since Gross Alpha and Gross Beta determinations are sensitive and economical in detecting radioactive contamination, their use for screening purposes is warranted.

Drinking water in northern Illinois has exceptionally high levels of radium-226 (Stehney, 1956 and Samuels, 1964). According to Samuels, about one million people in northern Illinois and southern Iowa drink water having a radium-226 concentration greater than 3pCi/l, and nearly 50,000 people drink water having a radium-226 concentration greater than 10 pCi/l. The normal intake of radium-226 is 2 pCi/l. Individuals who ingest 2 liters of water containing 10 pCi/l might be expected to receive a bone dose about ten times normal. Gilkeson, et al. (1978) have attempted to identify the source for the high levels of radium in Illinois ground water supplies. Water from municipal wells showed that 300 wells exceeded the 3 pCi/l upper limit for Gross Alpha activity in water. All of the affected wells were finished in bedrock, primarily of the Cambrian and Ordovician system of northern Illinois. The geologic settings where the wells are situated indicate that these high levels of Gross Alpha activity are probably not restricted to Illinois ground water sources. Gilkeson suggests that the source of radiation in this regional aquifer is due to the natural occurrence of uranium-238 and thorium-232.

Gesell, et al. (1978) have reviewed known concentrations of radon-222 in drinking water and have made some hypothetical predictions of health effects for exposed populations. Calculations indicate that water with 10,000 pCi/l radon-222 could produce an inhalation exposure of 80 mrem/wk (4 rem/yr) to the target organ of the bronchial epithelium, and an ingestion exposure of 25 mrem/wk to the stomach (if the daily ingestion is about 2 liters of water). If the potable water in dwellings contains a 500 pCi/l concentration of radon-222, a population living in these dwellings might experience 20 health effects (fatal lung cancers) per million persons exposed. These are only hypothetical estimates, so there is no existing standard for radon-222 in drinking water.

Water supplies from 225 North Carolina ground water supplies were assayed for radon-222 and approximately 33% of the water supplies were discovered to have concentrations greater than 2000 pCi/l. (Sasser, 1977)

DeVilliers and Windish (Eisenbud, 1973) have reported on elevated incidence of lung cancer among workers in flurospar mines. The apparent source of the radon in the mine was seepage of radon rich ground water. Once released from the water, radon daughter products contribute about

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*The Curie (Ci) is the unit used in measuring radio activity: the quantity of any radioactive atom of a specific nuclear constitution in which the number of disintegrations per second is 3.700×10^{10}. 1 picocurie (pCi) = 10^{-12} Ci.

20 times as much dose as does the original radon (Eisenbud, 1973).

Samples of drinking water from 827 world-wide Army installations were analyzed for 53 chemical and physical parameters (Sneeringer, 1977). Radiological activity appeared to vary with geographical location, with the majority of excessive levels (greater than 0.5 pCi/l Gross Alpha and/or greater than 0.7 pCi/l Gross Beta Activity) generated from Gross Alpha and Gross Beta "screening" determinations. No results for tritium were found to exceed the health reference limit of 216.0 pCi/l. One of the Army's sources was found to average 30 pCi/l. This high level was attributed to natural activity, and use of the source for human consumption was discontinued.

These studies suggest that a properly implemented water surveillance program cannot only protect the health of the immediate users but may also serve to generate a data base for broader epidemiologic studies.

The enactment of the National Interim Primary Drinking Water Regulations for Radioactivity (Sullivan, 1978) and the Safe Drinking Water Act of 1977 have facilitated the development and implementation of community drinking water monitoring programs. Most communities have developed a standard protocol of radiological sampling and analysis. The National Interim Primary Drinking Water Regulations for Radioactivity apply to community water systems serving residential structures and became effective on June 24, 1977.

Earlier studies of radiation in ground water were primarily geologically motivated. Sampling of water sources was not confined to potable water supplies. Even health motivated studies usually reported "wellhead" values rather than "at-the-tap" distribution system values, and the studies are concentrated in areas known to have high background radioactivity. Also, there had been incomplete geographic coverage (incomplete geologic aquifer coverage) of the United States. Therefore, until recently, pioneering work in the health implications of radioactivity in drinking water could not be generalized to large segments of the population in any meaningful fashion.

These studies and the development of the water surveillance systems offer the possibility for broad based epidemiologic studies of low dose ionizing radiation.

History of Early Disposal Operations

High rates of industrial production and civilian consumption in this country, coupled with an advancing technology, have created a radioactive refuse-disposal problem that threatens to outstrip waste handling resources and facilities in many communities. The need for further study of this situation is reflected in the Solid Waste Disposal Act signed by the President in October, 1965.

There are almost one thousand isotopes of some one hundred elements that are presently covered by Atomic Energy Commission regulations and licensing procedures. Wastes contaminated with these isotopes is generated in the forms of solids, gases, or liquids.

In addition, the energy levels of various radio-isotopes differ; some decay to safe levels more quickly than others, and each exhibits characteristic decay rates independent of pressure, temperature, or environment. Presently, solids constitute the greatest bulk and tonnage, liquids are measured in thousands of gallons per year depending upon the operation producing them, and radioactive gases are almost wholly nonexistent except those resulting from reactor operations.

The levels of activity of radioactive waste are termed "low, intermediate, or high". These terms are used without conciseness to describe different concentrations of radioactive materials in process wastes. This table can be seen on the following page.

When these definable limits are used, more than 99% of all military wastes by volume falls into the low level category (Dobyns, Gillespie, et al., 1966).

Beginning in 1946 (Dobyns, 1966), sea burial of solid, packaged material has been practiced as a disposal method in specific locations, generally off the continental shelves in waters of more than 1,000 fathoms, in both the

Atlantic and Pacific Oceans. Sea burial of licensed material has been generally discontinued, principally because of higher costs.

Table 1

RADIOACTIVE WASTE CATEGORIZATION

Activity	Level of Activity Solids (at emitting surface)	Liquids
High	2 R*/hr	1 mC/l
Intermediate	0.05 to 2R/hr	1 C/l but $<$1 mC/l
Low	0.05 R/hr	$<$ 1 C/l

*R = Roentgen, a unit of X-ray radiation: it is the amount of radiation given off to produce in 1 cc of air a sufficient degree of conductivity so that one electrostatic unit of charge may be measured at saturation. (See Footnote 1)

Prior to 1963, only sites supervised by the AEC were used for land burial of radioactive wastes. The AEC's Rules and Regulations, 10 CFR 20, detailed the procedures and standards established by the Commission which controlled waste disposal in the 50's and early 60's. From the beginning, the AEC recognized the practicality of burying radioactive wastes on land as a means of disposal and used selected areas as waste burial grounds at each of its major operating sites (Lennerman, 1967).

Today, complete lists of isotopes and radioactive materials approved by AEC licenses are maintained. Prior to 1958, individual military installations contacted the AEC directly in matters of license applications and complete categorization of wastes buried on military installations prior to 1958 is not possible. However, a majority of the wastes could be divided into three categories. The first was electron tubes containing small amounts of radioisotopes. Initially, these were used under terms of a general license issued by the AEC. Today, electron tubes may be disposed of locally at the originating site through normal base disposal or trash collection operations. Permission to dispose of electron tubes in this manner was granted by the Isotope Branch, Division of Licensing and Regulation, USAEC, on December 2, 1959. The second category was low-level wastes generated in nuclear weapons maintenance operations. The last category was radioactive self-luminous dials, which usually contained radium, strontium, or tritium.

Prior to 1959, the philosophy of ground disposal of radioactive waste was much less restrictive than it is today, but even the first edition of the Radiation Hygiene Handbook (Blatz, 1959) made forecasts for the effect of wastes disposal on water supplies:

> The magnitude of the problem of radioactive-wastes disposal in this country--from a nuclear-power industry with potentitial capacities approaching 175 million Kw by the year 1980--is such that the uncontrolled discharge of reactor fission-product wastes to the environment would be intolerable... Water is one of the nation's most valuable resources; water supplies relatively free from contamination are the life blood of municipalities and industries...In the past decade (prior to 1959) extremely dilute

> solutions of radioactive substances have been discharged to streams at such places as Hanford and Oak Ridge. Highly radioactive wastes from various plants of the Atomic Energy Commission have been stored in tanks so that none of the "hot" material has been released to streams or the atmosphere, but if storage should be continued to be utilized, the accumulated solutions of wastes could amount to 200 million gal by 1980 and 2,400 million gal by the year 2,000.

It seems ironic that the hydrogeologic factors which were considered to be critical for the site selection of nuclear plants were not equally considered in site selection for radioactive ground disposal (prior to 1959).

For instance, it was agreed that ground waters should be carefully investigated at any potential plant site to determine the characteristics of the water-bearing formation. The depth to ground water, the characteristics of the soils, and the rate at which water is moving through the aquifer were also investigated. In normal water-bearing materials, the natural gradients were calculated to be in the range from 0.001 to 0.1 (Theis, 1957). This gradient was considered to represent a fall in the ground water of 5 feet/mile. A good sandy aquifer was thereby predicted to transmit water under natural conditions at a rate close to 1 gal/day/square foot. Also, geologic factors were always considered in early plant selections. Interestingly enough, the corrosivity of soils was taken into account because underground storage tanks were generally included for the retention of liquid wastes at most early model nuclear energy plants. These same types of underground storage tanks were sometimes used in local ground disposal sites. Permeability and exchange capacity of the soils underlying the nuclear plant were carefully coordinated with the rate and flow of the ground waters. The possibility of these ground waters entering surface streams was carefully investigated. Therefore, it is apparent that early AEC policy reveals an indepth working knowledge of the hydrologic and the geologic considerations of ground water dynamics. However, attention to these considerations was more apparent in the selection of industrial plant sites than it was in the licensing of local radioactive ground disposal sites.

Twenty years later, these disposal sites (now closed) are still buried around us. The rate of decay of any radionuclide which could conceivably enter the ground water stream and the proximity of particular ground disposal sites to local public water supplies suggests the possible need for further evaluation. The association between the ground disposal of radioactive wastes and the radiological quality of public drinking water should be described to understand the impact of radioactive waste management on public health.

This study seeks, in part, to describe the radiological quality of drinking water with relation to the existent local radioactive ground disposal sites. It may be that other factors, both natural and man-controlled, are more integrally related to the level of radioactivity in a community's water supply. For instance, the existence of local conventional water treatment or the selection of the original type of water source for the community are two examples of man-controlled features which may be as important (or more so) as the existence of any local radioactive ground disposal site in affecting the level of measured radioactivity in municipal water supplies.

Hydrogeologic Considerations in the Ground Disposal of Radiological Wastes

There are three concepts basic to the handling and disposal of radioactive wastes:

(1) dilution and dispersion
(2) concentration and confinement
(3) delay and decay.

The public health implications of release to soil environments, especially the possible effects on population exposure is a matter of major public concern. We have had a little over 20 years' experience in the handling of radioactive wastes, yet we know comparatively little about the capacity of the environment to receive and to hold specific radionuclides. With the number of radionuclides which might be present, and with the many dynamic processes occurring in the hydrogeologic environment, it is readily apparent that the determination of potential exposure to population groups from the ground disposal of radioactive wastes presents a formidable task. Nevertheless, it is essential that the dynamics of radionuclide circulation in the ground water reservoirs must be understood before any realistic long-term prediction could be made. This would be particularly important in the calculation and interpretation of integrated radiological dose. For example, assume that the drinking water contains 50 pCi/l of strontium-90, and that the water intake of the adult male is 2 liters per day. Under these conditions, the thirty year integrated dose is 0.31 rem to the skeleton from strontium-90 (this figure utilizes updated dose codes provided by W. Phillips, Lawrence Livermore Laboratory, 1975). However, in calculation of such an integrated dose one must assume that the radionuclide levels in the source water remain unchanged with time except for loss due to radioactive decay. If the water concentrations either increase or decrease with time, the resulting real integrated dose will be changed proportionally. These changing conditions in ground water would depend on the soil burdens, the rates of leaching and ground water recharge, the ground water residence time, and other physical, biological and chemical factors.

Studies of operating waste burial grounds should be particularly concerned with the interactions of radionuclides in the waste with water and soil under natural conditions. It is important to estimate as closely as possible (1) the probably leaching of radionuclides from the wastes, (2) the ability of the soil materials to absorb the radioactive constitutents and prevent their movement in surface or ground water, and (3) the expected pattern of dispersion which might lead to exposures of people and potential radiation hazards. Shallow ground disposal is not considered safe for highly radioactive solid wastes because of the dangers of excessive dispersion of radionuclides to the environment.

In the early days of the atomic energy program, urgency and ignorance caused the burial of radioactive wastes in simple soil trenches within the restricted reservations of Manhattan District or other AEC installations. Even then, it was realized that the buried radionuclides might possibly be leached out by water or carried underground to contaminate ground water or emerge into surface water courses (See Figure 2).

For a number of years, certain AEC-licensed activities established facilities for burial of their own "on-site" wastes. In January, 1960, the AEC restricted waste burial locations to government-owned lands to assure future custody and responsible protection of public health and safety during the long periods of time in which a hazard from radioactivity of the buried waste might exist.

Site evaluation studies, particularly of the geology and hydrology, were not commonly undertaken for ground disposal sites during the 1950's.

As stated by Richardson, "The suitability of a site for land burial operations is completely dependent upon the ability of its environs to prevent the movement of activity

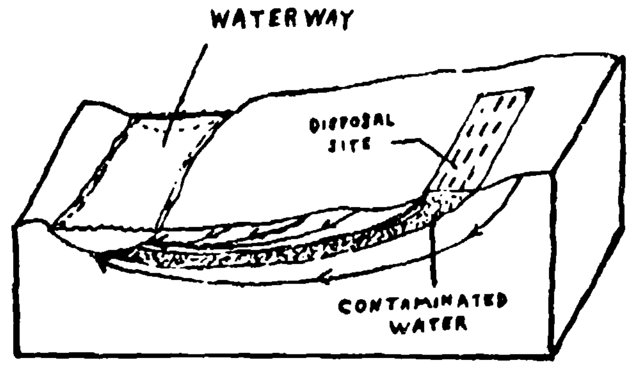

Figure 2.

Laminar Flow of Leachtate-Contaminated Ground Water

Leachtate is transmitted through the ground water by a definite flow path and is therefore not subject to dilution by the total amount of ground water within an aquifer between the disposal site and the ultimate ground water discharge point. Contaminated water does not always move with the major body of ground water.

This figure has been adopted from Figure 2, p. 223 of Drinking Water Quality Enhancement Through Source Protection, edited by Robert B. Pojasek, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

from point of burial to places where its presence might have adverse effects on man."

By 1968, solid radioactive wastes were disposed by burial in pits or trenches excavated in soil to depths generally not more than 20 feet. Critical elements of site evaluation criteria were developed and they included the following: (Peckham, Belter, Richardson, 1962).

(1) The only natural vehicle capable of transporting significant quantities of radionuclides away from a burial site is water, moving under the influence of gravity on and beneath the ground surface. Some determination of the amount of water, its direction and rate of movement at the site, and its movement as it leaves the site are all important factors for consideration (See figure 3). Additionally, Richardson (Richardson, 1963) has demonstrated that climate (particularly precipitation, temperature, and evapotranspiration) is an important influence on the movement of ground water and dissolved radionuclides at shallow depths below ground.

(2) Prolonged contact or soaking of the wastes in ground water should be avoided. The wastes should be located entirely in unsaturated soil. The maximum elevation of the ground water table should be sufficiently below the ground surface so that the buried wastes lie entirely in unsaturated soil.

(3) The principal mechanism that retards waterborne movement of radionuclides that may be leached from wastes buried in the ground is adsorption on soil and mineral particles. Accurate information is needed on the composition, permeability, porosity, and ion exchange properties of the overburden and bedrock at the burial site. The maximum elevation and fluctuations of the water table; the direction, slope and velocity of ground water movement; and the places where contaminated ground water might emerge at

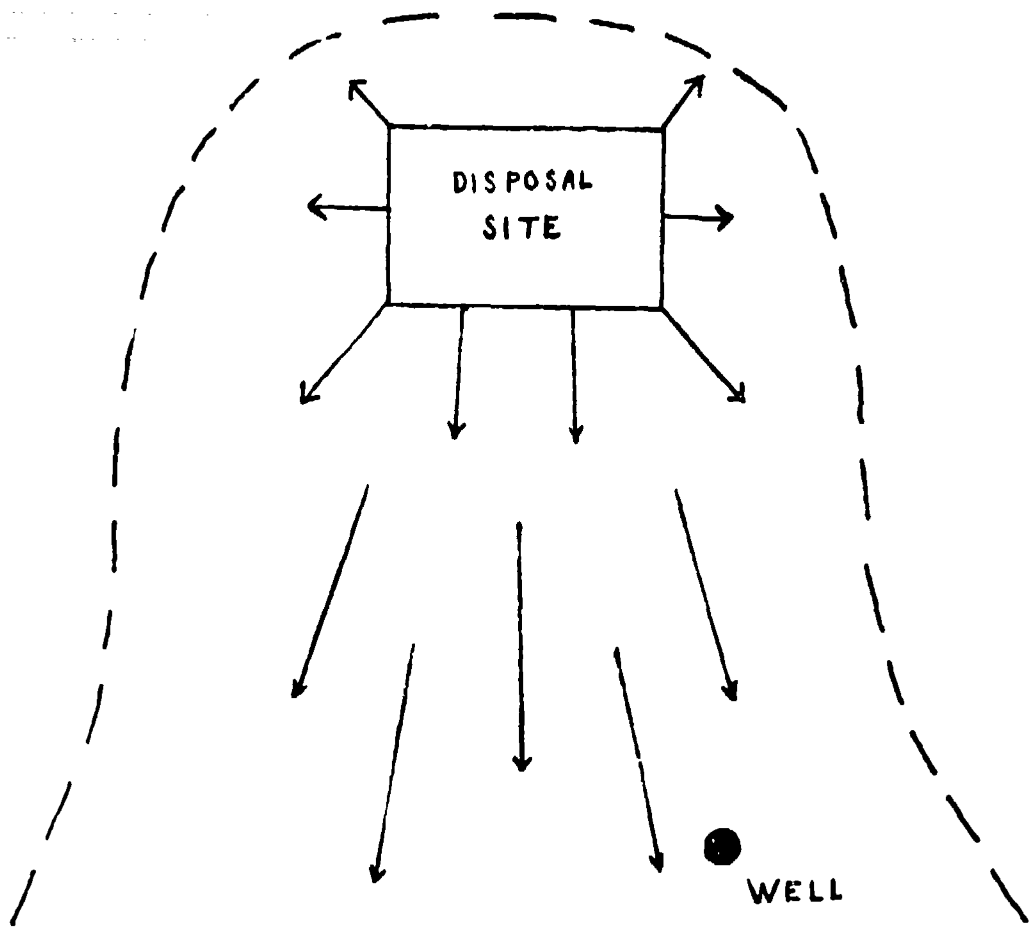

Figure 3.

Effects of Ground Water Movement on the Disposal of Radioactive Wastes to the Ground

The direction of ground water flow can be a significant factor in determining the isolation of wastes within a disposal site.

The principal illustrated here has been adopted from Figure 1, p. 218 of Drinking Water Quality Enhancement Through Source Protection, Edited by Robert B. Pojasek, Ann Arbor Publishers, Inc., Ann Arbor, Michigan.

the surface or where water might enter aquifers containing useful or potentially useful supplies of ground water.

(4) Each site's environment has inherent characteristics which must be studied and evaluated especially for that site. The suitability of a particular site should depend largely upon expert judgment supported by quantitative field and laboratory information.

Radiological safety generally denotes the prevention of human exposure to ionizing radiation in excess of limits prescribed by competent authorities. There are several recommended standards for maximum permissible exposures and several minimum requirements for radiation safety. Organizations which have adopted these recommended standards include the International Commission on Radiological Protection (ICRP), National Council on Radiation Protection and Measurements (NCRP), and the Federal Radiation Council (FRC). Generally, nuclear regulatory agencies (including the Atomic Energy Commission) have adopted the recommended standards. For practical applications a potential hazard menas that there is a possibility, though remote, of causing radiation exposures that do not comply with the requirements of the regulations (USAEC, 1966).

Ultimately, the maintenance of safety of the buried radioactive wastes depends upon containment of the radionuclides within the burial site; and this depends primarily upon climatic factors and the natural environment. Morton has summarized the probabilities of exposure to radiation because of the dispersion of buried radioactive materials

(Morton, 1968). Human exposure depends upon several factors: (1) the particular radionuclides and their quantities and concentrations as dispersed; (2) the manner and efficiency of contact with people, for example, through ingestion of contaminated drinking water, or food and milk, through inhalation, or by external dosage (e.g. bathing); (3) population density, which influences the number of people at risk of exposure; (4) distance from the burial site, which affects the amounts of dilution or radioactive decay before exposure; and (5) the degree and duration of human contacts through the particular exposure medium. The degree and importance of radiation exposure from buried radioactive wastes cannot be determined reliably except by a monitoring program.

CHAPTER III

GENERAL DESCRIPTION OF THE RADIOLOGICAL SURVEILLANCE OF DRINKING WATER BY THE AIR FORCE

The following is a brief description of the US Air Force drinking water radiological surveillance program. The procedure for monitoring and analyzing the radiological qualtiy of drinking water distributed at Air Force installations throughout the continental United States is outlined. Essentially, the USAF drinking water surveillance program implements the Safe Drinking Water Act (Public Law 93-523); the Environmental Protection Agency's National Interim Public Drinking Water Regulations (NIPDWR); and Department of Defense Directive 6230.1, 24 April, 1978. The USAF surveillance program applies to all drinking water systems of the US Air Force and Air Force Reserve.

The US Air Force Occupational and Environmental Health Laboratory (USAFOEHL), Brooks AFB, Texas 78235, has provided me with advice and guidance on sampling equipment instruments, laboratory methods, calibration, and interpretation of results which concern radiological monitoring data in this study. Air Force Regulation 161-44 (29 May 1979) has served as a useful reference for this description of the Air Force's monitoring program.

The USAFOEHL provides the services to complete all required laboratory radiological analyses and maintains a potable water quality data repository for the last ten years.

General Information on U.S. Air Force Water Sources

Ground water is found in those geologic formations that have internal structures permeable enough to allow appreciable quantities of water to move through them. Water enters those formations from natural or artificial recharge sources and percolates to either a natural or artificial opening where the water may be extracted. Ground water, when available in sufficient quantity is usually a preferred source of water supply. Such water can be expected to be clear, cool, colorless, and quite uniform in character. It is generally of a better bacterial quality and contains much less organic material than the surface water, but may be more highly mineralized. Surface water supplies are more readily subject to physical, bacteriological, and chemical contamination not usually associated with ground water sources. It is for these reasons that surface water has been used by the Air Force only when ground water sources were not economically available or were not adequate.

Radioactive elements can appear in water supplies as a result of fallout from nuclear explosions. Radioactive elements can also enter water from indiscriminate disposal of hospital of industrial radionuclides, as a result of leakage from the nuclear fuel cycle, or by the dissolution of naturally occurring radionuclides.

Radiological Standards Utilized by the Air Force in the Radiological Surveillance of Drinking Water

Radiological standards are based on the premise that radiation has an adverse physiological effect on humans and any unnecessary exposure should be avoided. The physiological effects of overexposure to radiation makes it essential to reject any treated water that has excess quantities of radionuclides. Proper treatment methods should be able to provide drinking water of desired radiological quality in most cases. The National Interim Public Drinking Water Regulations (NIPDWR) specify the following limits:

(1) Maximum contaminant levels for radium and Gross Alpha Particle Activity are:
   a. Combined radium-226 and radium-228.. 5 pCi/l
   b. Gross Alpha (include Ra-226 but exclude radon and uranium)...15 pCi/l

   Tritium and strontium-90 are exceptions to this standard. For these two radionuclides, the average annual concentrations assumed to produce a total body or organ dose of 4 mrem per year are as follows:

Radionuclide	Critical Organ	pCi/l
Tritium	Total Body	20,000
Strontium-90	Bone Marrow	8

(2) Maximum contaminant levels for Gross Beta Particle and photon radioactivity from man-made radionuclides in Air Force base water systems are as follows:
   a. The average concentration of beta particle and photon radioactivity from man-

made radionuclides in drinking water must not produce an annual dose equivalent to the total body, or to any internal organ, greater than 4 mrem per year.

b. The concentration of man-made radionuclides causing 4 mrem total body (or organ) dose equivalent is calculated on the basis of a 2 liter per day of drinking water intake, using the Maximum Permissible Concentration of Radionuclides in Air or Water for Occupational Exposure (National Bureau of Standards Handbook 69, as amended, August 1963, US Department of Commerce). If two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ must not be more than 4 mrem per year.

Drinking Water Sampling Performed in the Radiological Surveillance of Drinking Water by the Air Force

An analysis must be made on an annual composite of four consecutive quarterly samples, or the average of the analyses of four samples obtained at quarterly intervals. Each water distribution system must be monitored every four years. When the annual record shows that the average concentration is less than half the maximum contaminant levels, analysis of a single sample may be substituted for the quarterly sampling procedure.

Samples are collected in polyethylene, screwtop containers (such as Cubetainer[R]) and contain a minimum volume of 1000 ml or one US quart. No preservative is added. They are shipped by the most expeditious means to arrive at USAFOEHL.

An Air Force-wide schedule has been developed for the submission of samples from drinking water distribution monitoring locations for radiological analyses. Before 1978, water samples were submitted to USAFOEHL in an irregular and essentially randomized fashion. Beginning in January, 1978, a new sample submission schedule was instituted. Each distribution system submits four samples obtained at quarterly intervals. After completion of these samples per distribution system, samples would be submitted only every four years (assuming adequate radiclogical quality was found in these first samples).

Laboratory Methods Used in the Radiological Surveillance of Drinking Water by the Air Force

To determine compliance with radioactivity the methods specified in Radiochemical Methodology for Drinking Water. Environmental Monitoring and Support Laboratory, USEPA, EPA-600/4-75-008 were used (See Figure 4,5), or those listed below:

a. Gross Alpha and Beta: Method 302, "Gross Alpha and Beta Radioactivity in Water", Standard Methods for the Examination of Water, American Public Health Association, 13th Edition.
b. Total Radium: Method 304, "Radium in Water by Precipitation", Ibid.
c. Radium-226: Method 305, "Radium-226 by Radon in Water", Ibid.
d. Strontium-89-90: Method 303, "Total Strontium and Strontium-90 in Water", Ibid.

For monitoring radioactivity concentrations in drinking water, the required sensitivity of the radioanalysis is defined in terms of a detection limit. The detection

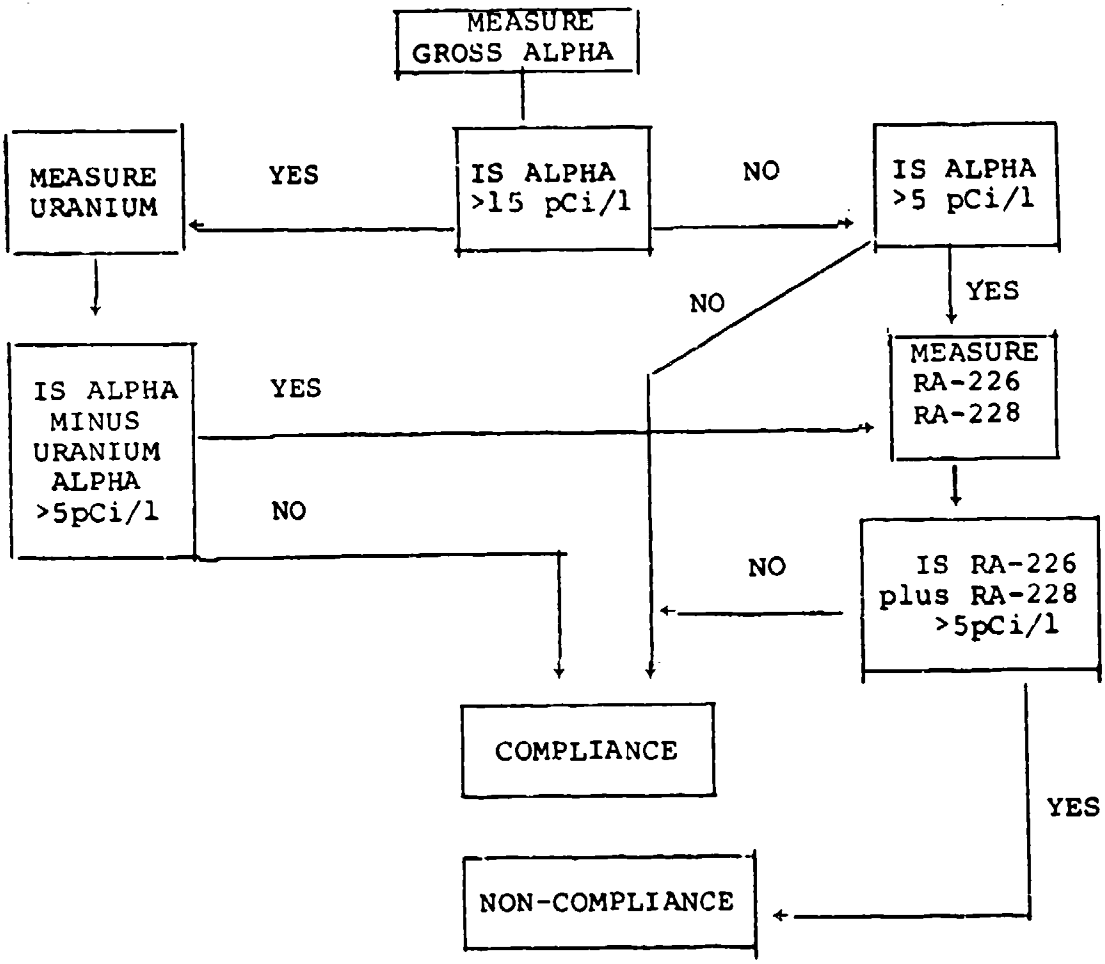

Figure 4

USAFOEHL Protocol for Monitoring Gross Alpha Particle Activity

This flow chart represents the analysis for Gross Alpha Particle as performed by the U.S. Air Force Occupational and Environmental Health Laboratory

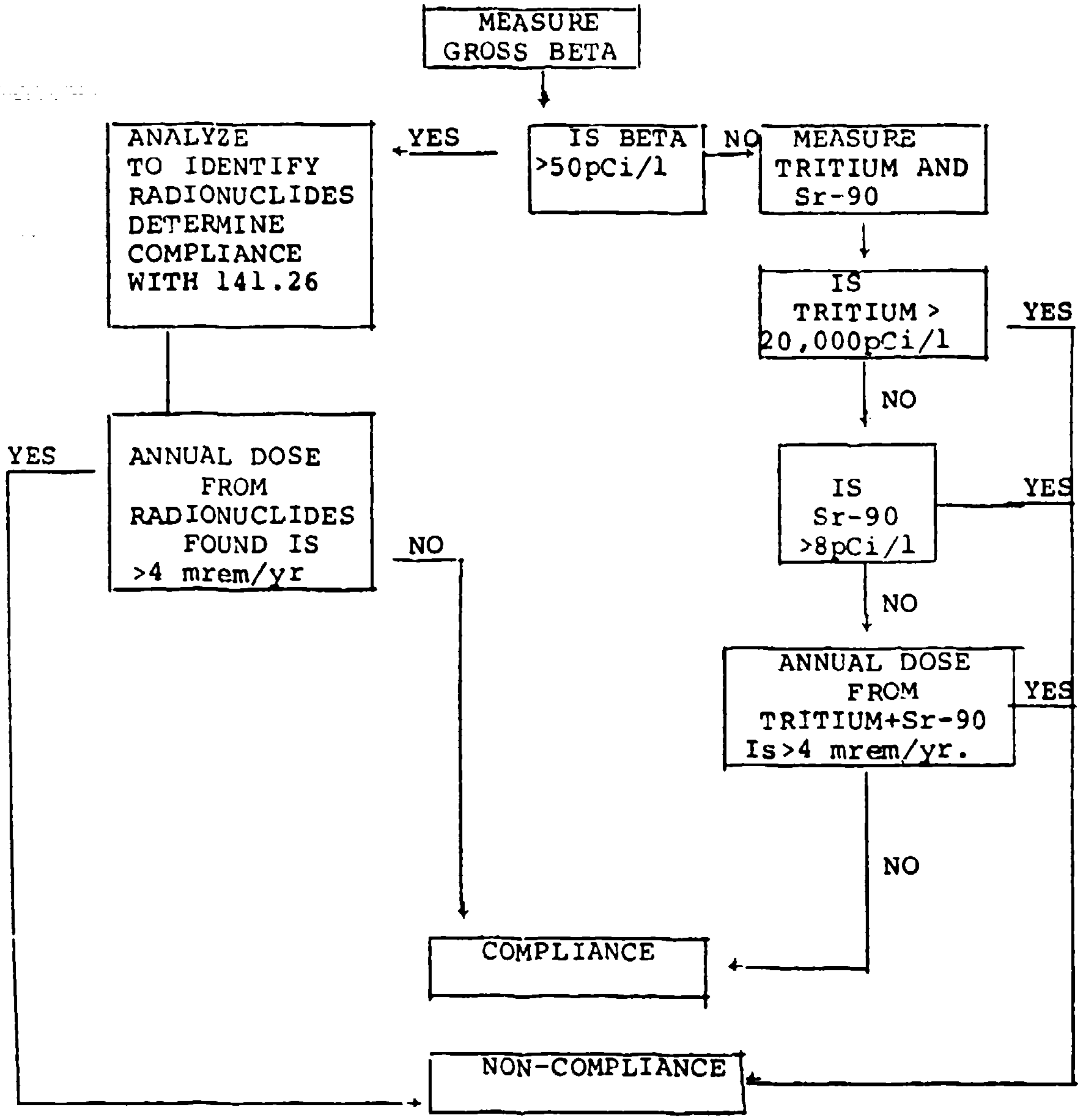

Figure 5

USAFOEHL Protocol for Monitoring Gross Beta Particle Activity

This flow chart presents the analysis for Gross Beta Particle Activity as performed by USAFOEHL.

limit is that concentration which can be counted with a precision of plus or minus 100 percent at the 95 percent confidence level (1.96δ where δ is the standard deviation of the net counting rate of the sample).

Commencing in January, 1978, a Gross Alpha Particle Activity measurement was substituted for the previously required radium-226 and radium-228 analyses, provided that the measured Gross Alpha Particle Activity does not exceed 5 pCi/l at a confidence level of 95 percent. In localities where radium-228 may be present in drinking water, analysis for radium-226 and radium-228 is conducted when the Gross Alpha Particle Activity exceeds 2 pCi/l. In addition, monitoring for man-made radioactivity is necessary in the following cases:

(1) If the base supply serves more than 100,000 persons.
(2) When the state requires it.
(3) When a surface water supply is contaminat d by effluents from nuclear facilities (i.e. nuclear power plants, fuel processing facilities, uranium mining operations, etc.) Currently, there is no known USAF drinking water system which meets any of these conditions.

Laboratory Measurement Equipment Utilized in the Radiological Surveillance of Drinking Water by the Air Force

Two types of proportional counters have been used in radioanalyses performed by USAFOEHL; a PC-5 Proportional Counting System (See Figure 6) and a Nuclear-Chicago Model 1152 Spectro/Shield Dector System (See Figure 7,8). The proportional counter is an ionization chamber type device

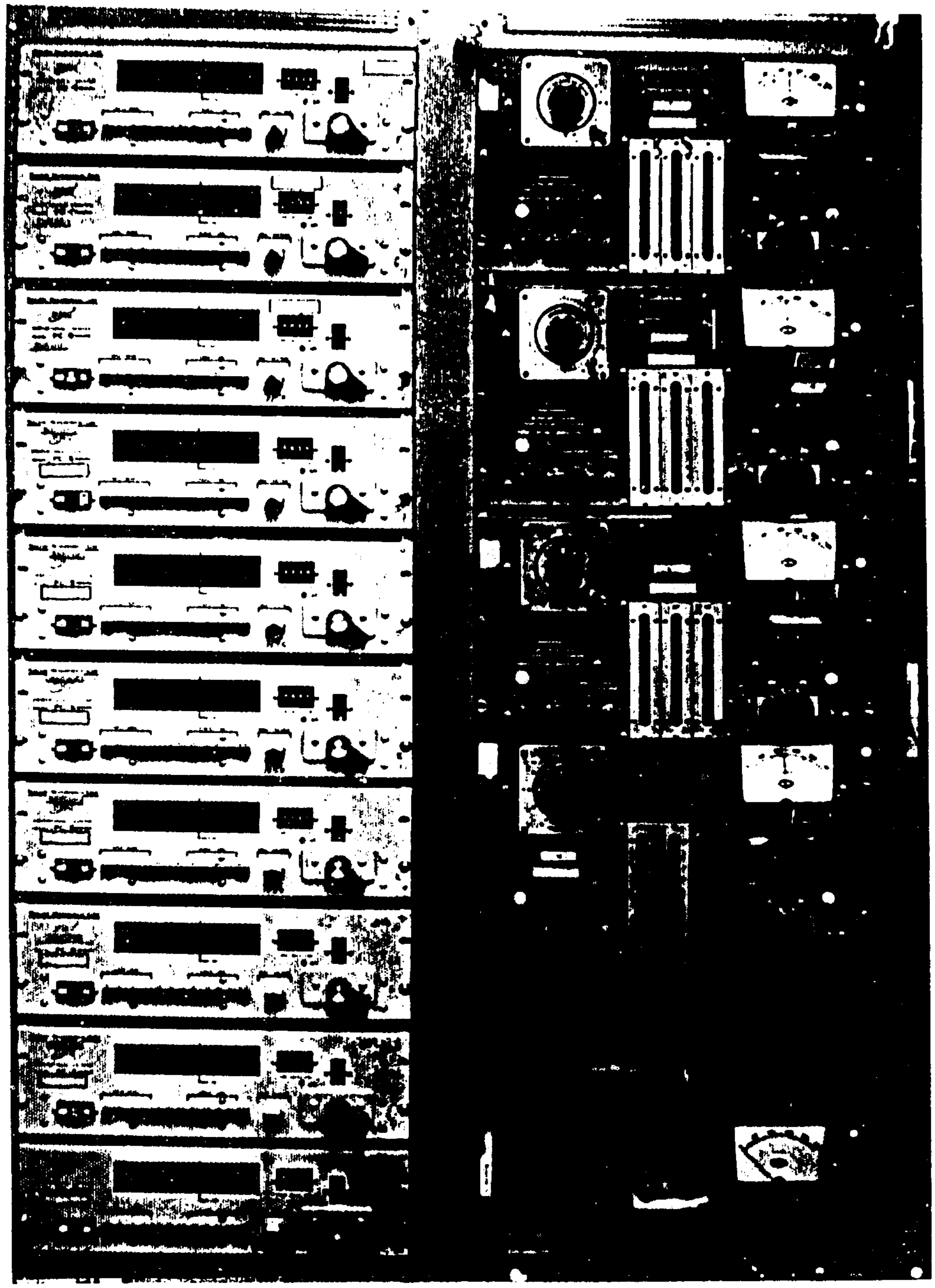

Fig. 6

The Nuclear Measurements Corporation
PC-5 Proportional Counting System

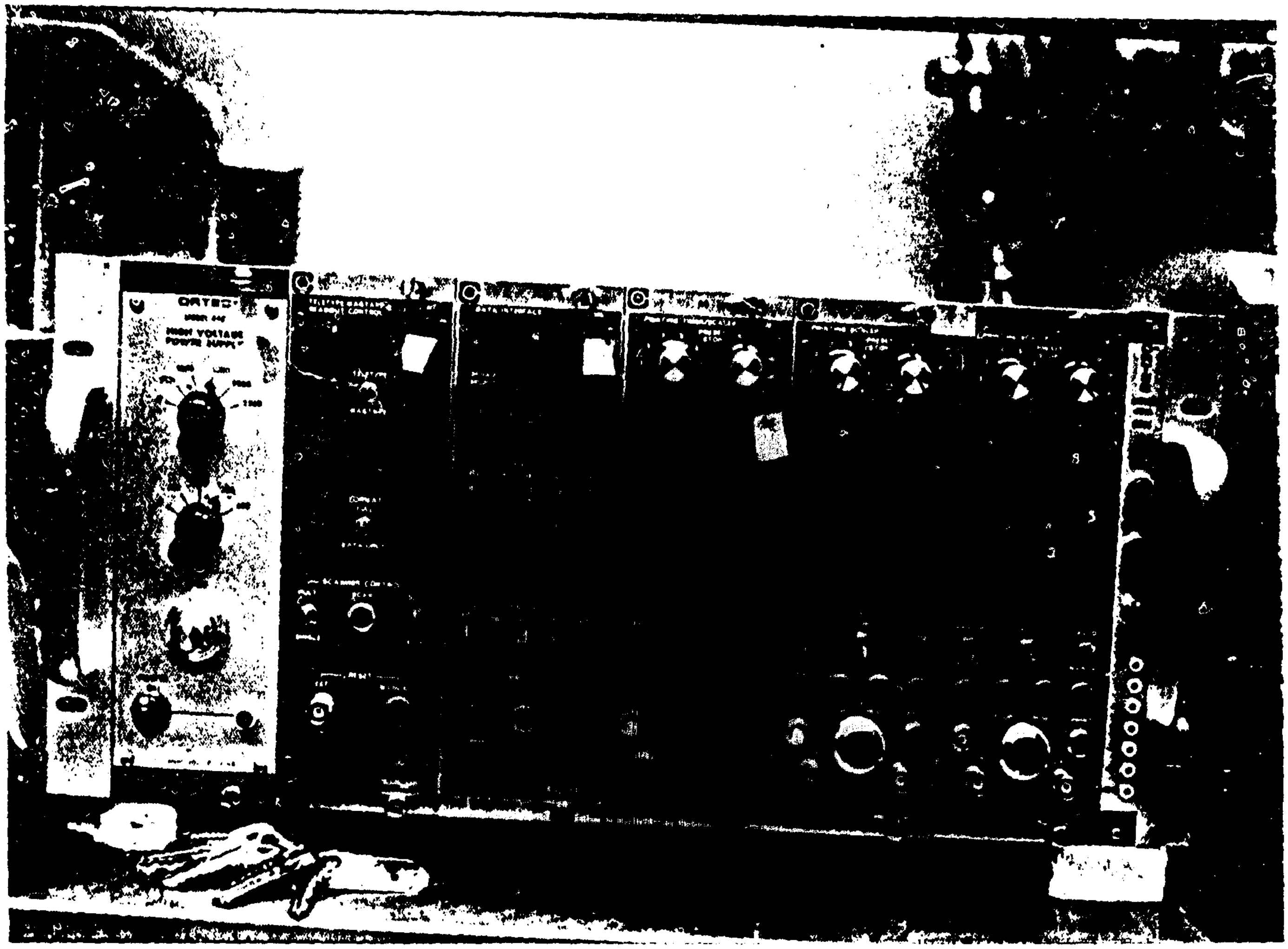

Fig. 8

High Voltage Power Supply for the Spectro Shield Automatic Sample Changer and Detection System

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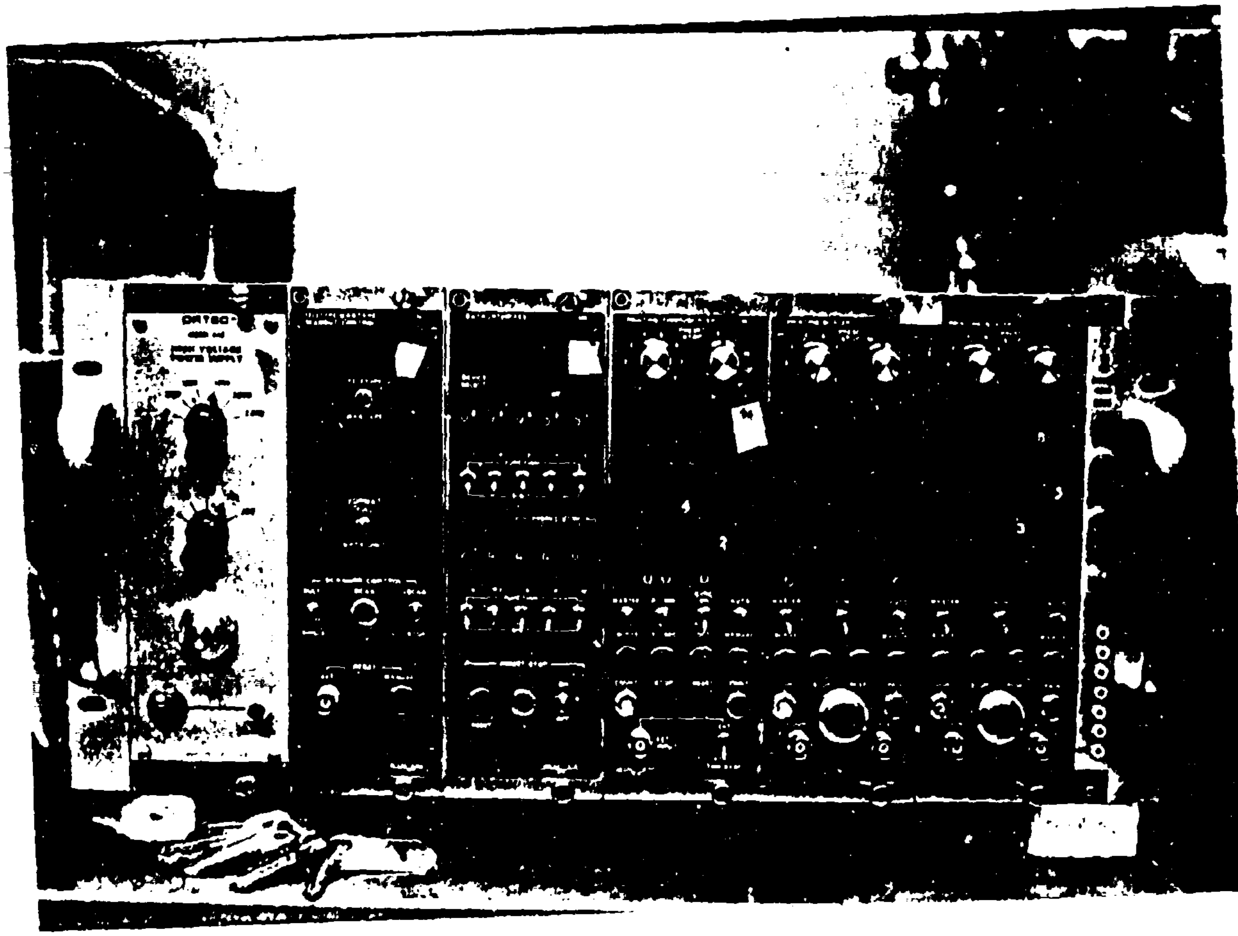

Fig. 8

High Voltage Power Supply for the
Spectro Shield Automatic Sample Changer
and Detection System

in which radiation is detected by the ionization of specially selected gases by collision with radiation particles or reaction with high energy electromagnetic rays (x-rays or gamma rays). The PC-5 is the sixth generation of proportional counting systems designed and built by Nuclear Measurements Corporation. The Nuclear-Chicago's Model 1152 Spectro/Shield is a fully automatic sample changer and detection system capable of counting up to 150 individual solid alpha and beta emitting samples on 2-inch diameter, or smaller, planchets.

CHAPTER IV

A DESCRIPTION OF THE LEVELS OF RADIOACTIVITY IN DRINKING WATER FROM SIXTY-FOUR COMMUNITIES (1974-1979)

Statistical Analysis of Available Data

Seven radioanalyses measured on samples from sixty-four Air Force base drinking water supplies, during 1974-1979 provide the data base for this study.

It is hypothesized that the level of radioactivity in drinking water might vary with each of three "predictor" variables. These variables are: presence of local water treatment, type of original water source, and the presence of a radioactive ground disposal site. Predictor variable information was available for sixty-four Air Force bases. These sixty-four Air Force Bases were classified using these three predictor variables.

The numbers in the table on the next page refer to numbers of bases.

It is noted that there is a small proportion (10/64) of the 64 bases which do not have conventional local water treatment. Hence, further evaluation of this predictor variable was not pursued in this study. Additionally, the category of "reservoir" was combined with that of "mixture

Table 2

Type of Drinking Water Source		Presence of Conventional Local Water Treatment		Presence of Radioactive Disposal Site Within the Community	
Well	34	Yes	54	Disposal	24
Reservoir	19	No	10	No Disposal	40
Mixture of Reservoir and Well	11				

of reservoir and well" because of the small proportion of "mixture" sources (11/64).

Further analysis of data in this study was directed in clarifying the following questions:

(1) Is there a relationship between the amount of radioactivity in drinking water and the type of source or the presence of a local radioactive disposal site?

(2) What is the form and strength of such a relationship when effects of the other predictor is taken into account?

(3) How well can drinking water radioactivity be explained by both predictors together?

(4) Are these relationships statistically significant?

The median measured value for each type of radioanalysis was calculated from all drinking water specimens submited to OEHL, 1974-1979. These median values were calculated from all drinking water specimens submitted to OEHL, 1974-1979. These specimens came from a total of 116 bases. Sixty-four of these bases are included in this study.

The types of radioanalysis, their respective detection limits, and their median measured values are as follows in the table below:

Table 3

Radioanalysis	Median Measured Value	Detection Limit (pCi/l)
Gross Alpha (combined)	2.0	1.0
Gross Alpha Dissolved)	3.0	1.0
Gross Alpha Suspended	0.2	0.1
Gross Beta Dissolved	6.0	3.0
Gross Beta Suspended	1.0	0.6
Radium	0.4	0.2
Strontium-90	2.2	1.5

The "Detection Limit" for each type of radioanalysis defined the separation between the category for less than detectable levels (LT) and the category for "greater than or equal to the detection limit" levels (GE).

In instances where multiple specimens for each type of radioanalysis had been submitted for a particular base, the median of these measurements was obtained and this level was used (for purposes of this study) as a level representative of that type of radioanalysis for that particular base. (If more than 50% of the measurements were in the "less than" category, the median was assigned to this category).

All available radioanalysis data for all sixty-four bases was utilized. However, data for each of the seven types of radioanalysis were not available for all of the bases studied. Three frequency tables were constructed for each type of radioanalysis. The first frequency table represents the distribution of the levels of drinking water radioactivity among bases with well supply sources. The second frequency table represents the distribution of levels of radioactivity among bases with either a reservoir source or a mixture of well and reservoir (in each such case water was primarily drawn from a reservoir supply). The third frequency table for each type of radioanalysis (titled SUM) collapses the first two tables of each set and does not differentiate on the basis of the type of original water source. The following set of frequency tables on page 48 were constructed.

Discussion of Statistical Analysis

This analysis has failed to detect any relationship between the amounts of radioactivity in the drinking water of these sixty-four communities and the predictor variables studied (type of source and the presence of a local radioactive disposal site). Seven types of radioanalysis were studied, and no relationship between these predictor variables and the levels of radioactivity in drinking water was detected.

Table 4

RADIOANALYSIS		WELL			RESERVOIR/ MIXTURE			SUM		
		LT	GE		LT	GE		LT	GE	
Gross Alpha (combined)	D	0	6	6	3	2	5	3	8	11
	N	5	6	11	3	2	5	8	8	16
		5	12	17	6	4	10	11	16	27
Gross Alpha Dissolved	D	3	5	8	2	6	8	5	11	16
	N	7	7	14	4	3	7	11	10	21
		10	12	22	6	9	15	16	21	37
Gross Alpha Suspended	D	5	3	8	6	2	8	11	5	16
	N	8	6	14	4	3	7	12	9	21
		13	9	22	10	5	15	23	14	37
Gross Beta Dissolved	D	6	2	8	6	2	8	12	4	16
	N	11	3	14	5	2	7	16	5	21
		17	5	22	11	4	15	28	9	37
Gross Beta Suspended	D	8	0	8	8	0	8	16	0	16
	N	9	5	14	6	1	7	15	6	21
		17	5	22	14	1	15	31	6	37
Radium	D	1	2	3	1	3	4	2	5	7
	N	3	5	8	2	0	2	5	5	10
		4	7	11	3	3	6	7	10	17
Strontium-90	D	8	0	8	6	2	8	14	2	16
	N	13	1	14	6	0	6	19	1	20
		21	1	22	12	2	14	33	3	36

D=Disposal LT=less than detectable level of radioactivity.
N=No Disposal GE=greater than or equal to the detection limit level of radioactivity

WELL

	LT	GE	
D	a_1	b_1	m_1
N	c_1	d_1	$t_1 - m_1$
	n_1	$t_1 - n_1$	t_1

RESERVOIR/MIXTURE

	LT	GE	
	a_2	b_2	m_2
	c_2	d_2	$t_2 - m_2$
	n_2	$t_2 - n_2$	t_2

SUM

LT	GE	
$a_1 + b_2$	$b_1 + b_2$	$m_1 + m_2$
$c_1 + c_2$	$d_1 + d_2$	...
$n_1 + n_2$	...	$t_1 + t_2$

For each of the seven sets of frequency tables, the following statistics were applied.

Q = Cochran-Mantel-Haenszel Chi-square statistic with 1 degree of freedom = CMH $-\chi^2$ (1) (not continuity corrected)

$$Q = \frac{(a_1 + a_2) - \left(\dfrac{m_1 n_1}{t_1} + \dfrac{m_2 n_2}{t_2}\right)}{\dfrac{n_1 m_1 (t_1 - m_1)(t_1 - n_1)}{t_1^2 (t_1 - 1)} + \dfrac{n_2 m_2 (t_2 - m_2)(t_2 - n_2)}{t_2^2 (t - 1)}}$$

and an overall estimate of the common odds ratio:

$$O = \frac{[(b_1 + \tfrac{1}{2})(c_1 + \tfrac{1}{2})]/t_1 + [(b_2 + \tfrac{1}{2})(c_2 + \tfrac{1}{2})]/t_2}{[(a_1 + \tfrac{1}{2})(d_1 + \tfrac{1}{2})]/t_1 + [(a_2 + \tfrac{1}{2})(d_2 + \tfrac{1}{2})]/t_2}$$

RADIOANALYSIS	OVERALL ODDS RATIO: 0	CMH-$\chi^2(1)$	pv
Gross Alpha (combined)	2.792	2.0426	$0.10<pv<0.20$
Gross Alpha (Dissolved)	3.825	1.4767	$0.20<pv<0.30$
Gross Alpha Suspended	0.660	0.6829	$0.40<pv<0.50$
Gross Beta Dissolved	1.049	0.0011	$0.90<pv<0.95$
Gross Beta Suspended	0.144	(4.6710)*	$0.025<pv<0.05$
Radium	2.574	1.2439	$0.20<pv<0.30$
Strontium-90	1.807	0.3557	$0.50<pv<0.60$

*The data available for the Gross Beta Suspended radioanalysis required the application of the Fisher-Irwin exact test for 2x2 tables. For the Gross Beta Suspended 2x2 titled "SUM", the two-tailed p-value is .047.

For the Gross Beta Suspended 2x2 tables titled "WELL" and "RESERVOIR/ MIXTURE, the Fisher-Irwin exact tests yield a probability of .035 for obtaining two zeroes in th ExD cells, giving a two-tailed p-value of .070.

CHAPTER V

DISCUSSION

It is noted that this study ignored the predictor variable of treatment because of the small proportion of bases which did not have locally available conventional water treatment. Proper treatment methods should be able to provide drinking water of the desired radiological quality in most cases.

Other possible contributors to the levels of radioactivity in drinking water were not investigated. These include, but are not restricted to, the indiscriminate disposal of hospital or industrial radionuclides, leakage from the nuclear fuel cycle, or the dissolution of naturally occurring radionuclides. Any one of these could conceivably account, in part, for the varying level of radioactivity in drinking water.

The numbers involved in this statistical analysis were too small to adequately control for the evaluation of all three "predictor variables" and to allow for more sensitive statistical analysis.

Ascertaining the levels of radioactivity in drinking water, and the association of these levels to certain variables, could involve a mathematical approach which is beyond the scope of this study. The dilemma faced by an uninitiated investigator can be characterized by an historical quotation:

> Mathematicians are like Frenchmen: whatever you say to them they translate into their own language, and forthwith it is something entirely different.
>
> Johann Wolfgang von Goethe
>
> (German poet and dramatist)
> 1749-1832

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VITA

John Robert Stockwell was born 28 July, 1947 in Spencer, West Virginia. His now deceased father, Hubert F. Stockwell, was a professional soldier. His mother, Hazel Stockwell (nee Bailey) lives in Valley Station, Kentucky.

John graduated from Fort Knox High School, Fort Knox, Kentucky, in June, 1965. He enlisted in the United States Air Force where he worked as an electronic digital computer repairman and obtained the rank of Sergeant. John returned to school on the GI Bill and in May, 1973, earned a Bachelor of Science degree in Medical Science from the University of Louisville, the nation's oldest municipal university. John continued his medical education at the University of Louisville and earned his MD degree in May, 1976.

John completed the first year of an AMA approved public health residency sponsored by the North Carolina Division of Health Services, Department of Human Resources. Dr. Isa C. Grant served as his program director. During this training John worked at the Guilford County Health Department, Greensboro, North Carolina (the nation's oldest county health department) under the preceptorship of Dr. Sarah T. Morrow. John also served on the staff of the nation's second oldest tuberculois sanatorium, McCain

Specialty Hospital, McCain, North Carolina, under the preceptorship of Dr. W.J. Steininger.

John joined the U.S. Air Force Medical Coprs in November, 1977, and served as a flight surgeon at Beale Air Force Base, California, the home base for the 9th Strategic Reconnaissance Wing which boasts the fastest and highest flying aircraft in the world (the SR-71), and the historic U-2. John was awarded the Air Force Commendation Medal for his meritorious service while assigned to Aeromedical Services, United States Hospital Beale. John is presently in a residency in Aerospace Medicine at the School of Aerospace Medicine, Brooks Air Force Base, Texas.

John and Helen Rosemary (nee Jackman), formerly of Louisville, Kentucky, were married in June, 1974. They have one daughter, Elizabeth Anne, who was born August 2, 1978.

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